

## **TITLE**

### **Structure For Reducing the Diffraction Effect in Periodic Electrode Arrangements and Liquid Crystal Device Including the Same**

## **BACKGROUND OF THE INVENTION**

### **Field of the Invention**

The present invention relates to a structure improving the light utilization rate of LCDs (Liquid Crystal Displays), and in particular to a structure for reducing the diffraction effect in periodic electrode arrangements and liquid crystal devices including the same. Transparent dielectric layers having different diffraction indices are formed between periodic electrodes and thickness of each transparent dielectric layer is adjusted so that optical paths of the incident lights at the passivation layers and the transparent electrodes are equal. Light collection efficiency is thus improved.

### **Description of the Related Art**

The display of light and dark on a thin film transistor liquid crystal display (TFT-LCD) is obtained by rotating the polarization direction of light, and by the birefringence characteristic of the liquid crystal. The main drawback of LCDs, when compared with self-illuminating displays, is narrow viewing angle, due mainly to do with the angle of incident light. Different viewing angles produce different display qualities, and

the greater the viewing angle, the lower the contrast between viewing angles.

Recently, lateral electric field has been applied as a method for improving viewing angle, contrast and response in LCDs. Lateral electric field is produced by arranging the direction of the electric field and the liquid crystal molecules on the same plane to drive the liquid crystal molecules. Phase differences caused by incident light on different viewing angles are thus reduced. With pixel electrodes and common electrodes simultaneously disposed on the TFT matrix substrate, this method features larger viewing angle of liquid crystal display. In addition, electrodes are periodically disposed and the electric field parallels the panel.

Lateral electric field mode is suitable for transmissive, reflective and semi-transparent displays. Active driven techniques are well suited for semi-transparent displays, and exhibit advantages of both reflective and transmissive displays, such as amorphous-silicon TFT or low temperature polysilicon TFT. Therefore, current low-consumption IA products typically employ semi-transparent display panels. Electrodes, however, can only be placed on one side of the two substrates and strips of electrodes must be arranged periodically when applying lateral (horizontal) electric field. This is problematic as diffraction indices in periodic electrode arrangements and the surrounding dielectric material are different, thus incident light diffraction occurs. Consequently, the light utilization rate is reduced and stray light within the system further

hinders display contrast. For projection systems, in particular, only reflected lights with smaller angles are collected, diffracted lights with greater angles lower the illumination efficiency considerably.

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### **SUMMARY OF THE INVENTION**

Accordingly, an object of the invention is to provide a structure for reducing the diffraction effect in periodic electrode arrangements and liquid crystal displays including the same.

In order to achieve the above object, the invention provides a structure for reducing the diffraction effect in periodic electrode arrangements, which features a novel structure comprised of dielectric materials and electrodes to prevent reduced illumination efficiency due to light diffraction caused by periodic electrode arrangements. The outcome includes higher light utilization rate and enhanced display quality.

The novel structure comprises dielectric materials and electrodes utilizing multiple (two or more) layers of transparent dielectric materials having different diffraction indices formed between periodic electrodes. Thicknesses for various transparent dielectric layers are modified so that the optical paths of the incident lights at the passivation layers or the transparent electrodes are identical. The angle of stray light and diffracted lights is reduced, thus solving the problem of reduced illumination efficiency associated with light diffraction.

The thickness of various transparent dielectric layers is modified in such a way that the diffraction index and thickness of the various dielectric layers and the transparent electrodes satisfy the following formula (I):

$$0.8 n_{ed}d_{ed} \leq n_1d_1+n_2d_2+\cdots+n_xd_x \leq 1.2 n_{ed}d_{ed}$$

wherein  $n_1$  is the diffraction index of the first dielectric layer,  $n_2$  is the diffraction index of the second dielectric layer,  $n_x$  is the diffraction index of the  $x^{th}$  dielectric layer,  $n_{ed}$  is the diffraction index of the transparent electrode,  $d_1$  is the partial or overall thickness ( $\mu m$ ) of the first dielectric layer,  $d_2$  is the partial or overall thickness ( $\mu m$ ) of the second dielectric layer,  $d_x$  is the partial or overall thickness ( $\mu m$ ) of the first dielectric layer, and  $d_{ed}$  is the thickness ( $\mu m$ ) of the transparent electrode.

A detailed description is given in the following embodiments with reference to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The present invention can be more fully understood by reading the subsequent detailed description and examples with references made to the accompanying drawings, wherein:

Fig. 1 is a schematic top view showing a lower substrate of a conventional IPS type LCD;

Fig. 2 is cross section along the line II-II' in Fig. 1;

Fig. 3 is cross section of the lower substrate of the first embodiment of the invention;

Figs. 4a to 4e are flowcharts showing the process of the first embodiment of the invention;

5 Fig. 5 is cross section of the lower substrate of the second embodiment of the invention;

Fig. 6 is cross section of the lower substrate of the 3<sup>rd</sup> embodiment of the invention;

10 Fig. 7 is cross section of the lower substrate of the fourth embodiment of the invention;

Figs. 8a to 8e are flowcharts showing the process of the fourth embodiment of the invention;

Figs. 9a to 9e are flowcharts showing the process of the fifth embodiment of the invention;

15 Fig. 10 is an exploded schematic view of a liquid crystal display (LCD).

#### REFERENCE NUMERALS IN THE DRAWINGS

10 dielectric layer  
20 first transparent dielectric layer  
20 21 dielectric layers  
22 second transparent dielectric layer  
23 dielectric layer  
24 third transparent dielectric layer  
30 alignment layer  
25 40 first electrode  
42 second transparent electrode  
50 second electrode  
52 second transparent electrode

$d_1$  partial or overall thickness of the first dielectric layer

$d_2$  partial or overall thickness of the second dielectric layer

$d_{ed}$  thickness ( $\mu m$ ) of the transparent electrode

$d_{ed1}$  predetermined thickness

$d_{ed2}$  predetermined thickness

### DETAILED DESCRIPTION OF THE INVENTION

The invention provides a structure for reducing the diffraction effect caused by periodic electrode arrangements in lateral (horizontal) electric field. The conventional protective dielectric layers are replaced by multiple (two or more) layers of transparent dielectric materials with different diffraction indices. These transparent dielectric layers are formed among the periodic electrodes. Thickness of various transparent dielectric layers is modified so that the diffraction index and thickness of various dielectric layers and the transparent electrodes satisfy the following formula (I). Optical paths of the incident lights at the electrode protective layers and the transparent electrodes are identical.

Formula (I):

$$0.8 n_{ed} d_{ed} \leq n_1 d_1 + n_2 d_2 + \dots + n_x d_x \leq 1.2 n_{ed} d_{ed}$$

wherein  $n_1$  is the diffraction index of the first dielectric layer,  $n_2$  is the diffraction index of the second dielectric layer,  $n_x$  is the diffraction index of

the  $x^{\text{th}}$  dielectric layer,  $n_{\text{ed}}$  is the diffraction index of the transparent electrode,  $d_1$  is the partial or overall thickness ( $\mu\text{m}$ ) of the first dielectric layer,  $d_2$  is the partial or overall thickness ( $\mu\text{m}$ ) of the second dielectric layer,  $d_x$  is the partial or overall thickness ( $\mu\text{m}$ ) of the first dielectric layer, and  $d_{\text{ed}}$  is the thickness ( $\mu\text{m}$ ) of the transparent electrode.

The invention also features a structure for reducing the diffraction effect in periodic electrode arrangements operating under In Plane Switching (IPS) mode, or the so-called lateral electric field mode. The original protective dielectric layers are now substituted by multiple (two or more) layers of transparent dielectric materials having different diffraction indices. These transparent dielectric layers are disposed among the periodic electrodes. Thickness of the various transparent dielectric layers is modified so that the diffraction index and thickness of various dielectric layers and the transparent electrodes satisfy the following formula (I). Optical paths of the incident lights at the electrode protective layers and the transparent electrodes are identical.

In a preferred embodiment, the invention also provides a structure for reducing the diffraction effect in periodic electrode arrangements operating in fringe-field switching mode.

Dielectric layers in this invention are also used as dielectric material for protecting electrodes. The dielectric layers are preferably transparent dielectric materials, such as silicon-rich oxides or nitrides formed

by CVD, titanium dioxide, zinc oxide, Cerium dioxide, Zinc sulfide or fluorine-containing glass.

In the invention, dielectric layers comprising two or more layers are disposed among periodic electrodes.

Periodic electrodes in the invention are preferably transparent electrodes, such as ITO, IZO, AZO or ZnO.

The invention provides a structure for reducing the diffraction effect in periodic electrode arrangements. The novel structure is obtained by forming multiple (two or more) transparent dielectric layers among periodic electrodes and modifying the thickness of the various transparent dielectric layers. Therefore, optical paths of the incident lights at the various dielectric layers and the transparent electrodes are identical. The structure provided in the invention is applicable for LCDs with periodic electrode arrangements operated in lateral electric field, IPS or FFS mode.

#### **First Embodiment**

Fig. 2 is a cross section along the line II-II' of the lower substrate in Fig. 1. The second electrode 50 is a transparent electrode, and the dielectric layer 23 is a transparent dielectric layer. Due to different optical paths of incident lights, light diffracts due to the diffraction effect in this periodic electrode arrangements.

The first embodiment is designed to reduce the diffraction effect for the structure described above. Fig. 3 is a cross section showing the lower substrate of the first embodiment of the invention. In Fig. 4a, a



dielectric layer 10 having first electrodes 40 formed thereon is provided, and a first transparent dielectric layer 20 is formed to cover the first electrodes. A second transparent dielectric layer 22 having a predetermined thickness  $d_1$  is then formed on the first transparent dielectric layer 20, as shown in FIG. 4b.

Then, the second transparent dielectric layer 22 is etched using the first transparent dielectric layer 20 as an etch stop layer, thus defining transparent electrode areas, as shown in FIG. 4c. A second transparent electrode 52 is then formed in the transparent electrode areas. That is, the second transparent electrode 52 with a predetermined thickness  $d_{ed}$  is formed in the etched areas in the second transparent dielectric layer, as shown in Fig. 4d.

A third transparent dielectric layer is then plated on the second transparent electrode 52 and the second transparent dielectric layer 22, followed by etching using the second transparent dielectric layer 22 as an etch stop layer. The third transparent dielectric layer 24 is shown in Fig. 4e. Finally, an alignment layer 30 is formed.

In this embodiment, the first electrode 40 is aluminum, the second transparent dielectric layer 22 is silicon oxide, having a diffraction index of  $n_1$ . The third transparent dielectric layer 24 is silicon dioxide having a diffraction index of  $n_2$ . The second transparent electrode 52 is ITO glass having a diffraction index of  $n_{ed}$ . Thickness of the second transparent dielectric layer 22 and the second transparent electrode 52 is  $d_1$  ( $\mu\text{m}$ ), and

$d_{ed}$  ( $\mu\text{m}$ ) respectively. Thickness of the third transparent dielectric layer 24 is  $d_2$  ( $\mu\text{m}$ ), i.e.  $d_{ed}-d_1$  ( $\mu\text{m}$ ).

$n_1$ ,  $n_2$ ,  $n_{ed}$ ,  $d_1$ ,  $d_2$  and  $d_{ed}$  satisfy the following formula (II):

$$n_1 d_1 + n_2 d_2 = n_{ed} d_{ed}$$

### **Second Embodiment**

Fig. 2 is cross section along the line II-II' of the lower substrate in Fig. 1. The second electrode 40 is a transparent electrode, and the dielectric layers 21 and 23 are transparent dielectric layers. Due to different optical paths of incident lights, light diffracts due to the diffraction effect in this periodic electrode arrangements.

The second Embodiment is designed to solve the diffraction problem in the above structure. Fig. 5 is cross section showing the lower substrate of the second embodiment of the invention. A transparent dielectric layer 20 having a predetermined thickness  $d_1$  is formed on a dielectric layer 10, followed by etching the first transparent dielectric layer 20 to define the transparent electrode areas. Transparent electrodes 42 are then plated onto the transparent electrode areas.

The second transparent electrode 42 is then etched using the first transparent dielectric layer 20 as an etch stop layer, thus forming a transparent electrode 42 having a predetermined thickness  $d_{ed}$ .

Electrodes 50 are then formed on the electrode areas in the first transparent dielectric layer 20, followed by

the formation of a second transparent dielectric layer 22. Finally, an alignment layer 30 is formed.

In this embodiment, the first transparent electrode 42 is ITO having a diffraction index of  $n_{ed}$ , and the first transparent dielectric layer 20 is titanium dioxide with a diffraction index of  $n_1$ . The second transparent dielectric layer 22 is silicon dioxide having a diffraction index of  $n_2$ . The second electrode 50 is transparent ITO. Thickness of the first transparent dielectric layer and the first transparent electrode 42 is  $d_1$  ( $\mu\text{m}$ ), and  $d_{ed}$  ( $\mu\text{m}$ ) respectively. Thickness of the second transparent dielectric layer 22 is  $d_2$  ( $\mu\text{m}$ ), i.e.  $d_{ed}-d_1$  ( $\mu\text{m}$ ).

$n_1$ ,  $n_2$ ,  $n_{ed}$ ,  $d_1$ ,  $d_2$  and  $d_{ed}$  satisfy the following formula (III):

$$n_1 d_1 + n_2 d_2 = n_{ed} d_{ed}$$

### **Third Embodiment**

Fig. 2 is cross section along the line II-II' of the lower substrate in Fig. 1. The first electrode 40 and the second electrode 50 are transparent electrodes, and the dielectric layers 21 and 23 are transparent dielectric layers. Due to different optical paths of incident lights, light diffracts due to the diffraction effect in this periodic electrode arrangement.

The third embodiment is designed to reduce the diffraction effect in the above structure. Fig. 6 is cross section showing the lower substrate of the 3<sup>rd</sup> embodiment of the invention. A transparent dielectric layer 20 having a predetermined thickness  $d_1$  and a first

transparent electrode 42 having a predetermined thickness  $d_{ed1}$  are formed on a dielectric layer 10. A second transparent dielectric layer 22 having a predetermined thickness  $n_2$  is then formed on the first transparent dielectric layer 20 and the first transparent electrode 42.

The second transparent dielectric layer 22 is etched using the first transparent dielectric layer 20 as an etch stop layer to define the transparent electrode areas. Second transparent electrodes 52 having a predetermined thickness  $d_{ed2}$  are then plated onto the transparent electrode areas.

A third transparent dielectric layer 24 is then formed on the second transparent electrode 52 and the second transparent dielectric layer 22. Finally, an alignment layer 30 is formed, as shown in Fig. 6.

In this embodiment, the first transparent electrode 42 is ITO having a diffraction index of  $n_{ed1}$ , and the second transparent electrode 52 is IZO having a diffraction index of  $n_{ed2}$ . The first transparent dielectric layer 20 is silicon oxide with a diffraction index of  $n_1$ . The second transparent dielectric layer 22 is silicon dioxide having a diffraction index of  $n_2$ . The third transparent dielectric layer 24 is titanium dioxide having a diffraction index of  $n_3$ . Thickness of the first transparent dielectric layer and the first transparent electrode 42 is  $d_1$  ( $\mu\text{m}$ ), and  $d_{ed1}$  ( $\mu\text{m}$ ) respectively. Thickness of the second transparent electrode 52 is  $d_{ed2}$  ( $\mu\text{m}$ ). Thickness of the second transparent dielectric layer 22 is  $d_2$  ( $\mu\text{m}$ ), i.e.  $d_{ed1}-d_1$  ( $\mu\text{m}$ ). Thickness of the

third transparent dielectric layer 24 is  $d_3$  ( $\mu\text{m}$ ), i.e.  $d_{\text{ed}2}-d_2$  ( $\mu\text{m}$ ).

$n_1$ ,  $n_2$ ,  $n_{\text{ed}1}$ ,  $n_{\text{ed}2}$ ,  $d_1$ ,  $d_2$ ,  $d_{\text{ed}1}$  and  $d_{\text{ed}2}$  must satisfy the following formula (IV):

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$$n_1d_1 + n_2d_2 + n_3d_3 = n_{\text{ed}1}d_{\text{ed}1} + n_3d_3 = n_{\text{ed}2}d_{\text{ed}2} + n_1d_1$$

#### **Fourth Embodiment**

Fig. 7 illustrates the structure for reducing the diffraction effect in a periodic electrode arrangement operating in fringe-field switching mode.

10 First, a dielectric layer 10 having first electrodes 40 formed on the surface is provided. A first transparent dielectric layer 20 is then formed on the first dielectric layer 10 to cover the first transparent electrodes 40, as shown in Fig. 8a. In Fig. 8b, a second transparent electrode 52 having a predetermined thickness  $d_{\text{ed}}$  is formed. Next, the second transparent electrode 52 is etched using the first transparent dielectric layer 20 as an etch stop layer to define the second transparent electrode 52, as shown in Fig. 8c.

20 A second transparent dielectric layer 22 is then plated, followed by etching to form a second transparent dielectric layer 22 having a predetermined thickness  $n_1$  between the second electrodes 52, as shown in FIG. 8d. A third transparent dielectric layer 24 is then formed to cover the second electrodes 52 and the second transparent dielectric layer 22, as shown in Fig. 8e. Finally, an alignment layer 30 is formed.

30 In this embodiment, the first transparent electrode 40 is aluminum and the second electrode 22 is titanium

dioxide having a diffraction index of  $n_1$ . The third transparent dielectric layer 24 is silicon dioxide with a diffraction index of  $n_2$ . The second transparent electrode 52 is ITO glass having a diffraction index of  $n_{ed}$ . Thickness of the second transparent dielectric layer and the second transparent electrode 52 is  $d_1$  ( $\mu\text{m}$ ), and  $d_{ed}$  ( $\mu\text{m}$ ) respectively. Thickness of the third transparent dielectric layer 24 is  $d_2$ , i.e.  $d_{ed}-d_1$  ( $\mu\text{m}$ ).

$n_1$ ,  $n_2$ ,  $n_{ed1}$ ,  $n_{ed2}$ ,  $d_1$ ,  $d_2$ ,  $d_{ed1}$  and  $d_{ed2}$  must satisfy the following formula (IV):

$$n_1 d_1 + n_2 d_2 = n_{ed} d_{ed}$$

#### **Fifth Embodiment**

The fifth embodiment is an alternative process for forming the structure of the lower substrate described in the fourth embodiment.

First, a dielectric layer 10 having first electrodes 40 formed on the surface is provided. A first transparent dielectric layer 20 is then formed on the first dielectric layer 10 to cover the first transparent electrodes 40, as shown in Fig. 9a. In Fig. 9b, a second dielectric layer 22 having a predetermined thickness  $d_1$  is formed. Next, the second transparent dielectric layer 22 is etched using the first transparent dielectric layer 20 as an etch stop layer to define the electrode areas, as shown in Fig. 9c.

Second transparent electrodes 52 having a predetermined thickness  $d_{ed}$  are then plated on the electrode areas in the second transparent dielectric layer 22. Etching is then performed using the second

transparent dielectric layer 22 as the etch stop layer to form the second transparent electrodes 52 shown in Fig. 9d. A third transparent dielectric layer 24 is then formed to cover the second electrodes 52 and the second transparent dielectric layer 22, as shown in Fig. 9e. Finally, an alignment layer 30 is formed.

In this embodiment, the first transparent electrode 40 is aluminum and the second transparent dielectric 22 is titanium dioxide having a diffraction index of  $n_1$ . The third transparent dielectric layer 24 is silicon dioxide with a diffraction index of  $n_2$ . The second transparent electrode 52 is ITO having a diffraction index of  $n_{ed}$ . Thickness of the second transparent dielectric layer and the second transparent electrode 52 is  $d_1$  ( $\mu\text{m}$ ), and  $d_{ed}$  ( $\mu\text{m}$ ) respectively. Thickness of the third transparent dielectric layer 24 is  $d_2$ , i.e.  $d_{ed}-d_1$  ( $\mu\text{m}$ ).

$n_1$ ,  $n_2$ ,  $n_{ed}$ ,  $d_1$ ,  $d_2$ , and  $d_{ed}$  must satisfy the following formula (V):

$$n_1 d_1 + n_2 d_2 = n_{ed} d_{ed}$$

In summary, the advantages of the invention include the following. Reduced diffraction effect in periodic electrode arrangements for lateral electric field (pixel electrodes and common electrodes are disposed simultaneously on the TFT matrix substrate), thus increasing light utilization rate. Improving the reduced contrast caused by diffraction effect when using an IPS type LCD, while increasing the viewing angle to  $170^\circ$ . Reducing the diffraction effect caused by large-angle diffraction light in projection systems where only

diffracted lights with smaller angles are collected, thus greatly enhancing the light collection efficiency thereof.

5 While the invention has been described by way of example and in terms of the preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. To the contrary, it is intended to cover various modifications and similar arrangements (as would be apparent to those skilled in the art).  
10 Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.